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AN INVESTIGATION OF THE NONTECHNICAL SKILLS REQUIRED TO MAXIMIZE THE SAFETY AND PRODUCTIVITY OF U.S. NAVY DIVERS

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Although the diving community is proficient in identifying and mitigating technical problems, it is not as adept in recognizing and reducing the nontechnical human factors errors that cause accidents. Through using multifaceted methods to collect data with both quantitative and qualitative techniques, this study aims to improve our understanding of the nontechnical skills required to conduct safe and effective diving operations. The collected data demonstrate that diving supervisors and diving officers in particular can benefit from instruction in leadership, development and maintenance of situation awareness, risk and time assessment, effects of personal limitations on performance, and ways that these skills contribute to safe, effective diving operations.

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INTRODUCTION

Although U.S. Navy diving is remarkably safe, because of the high-risk environment in which the divers work, accidents and mishaps do occur. The U.S. Navy diving community is adept at identifying and mitigating technical problems. However, it is not as adept with the nontechnical or human factors that cause accidents. Safety research has shown that human performance problems most heavily shape risks in hazardous industries: the greatest cause of approximately 80% of naval aviation mishaps is generally regarded as human error.[1,2] Nevertheless, little guidance to prevent or mitigate such accidents is available to divers.

The aviation industry has developed human factors training programs known as crew resource management (CRM) to improve the effectiveness of aviation missions by minimizing preventable crew errors, maximizing crew coordination, and optimizing risk management.[3] Air crew coordination training (as the Navy calls CRM) is designed to develop skills in decision making, assertiveness, mission analysis, communication, leadership, adaptability/flexibility, and situational awareness.[4] The content of aviation CRM training is based on analyses of behavioral skills commonly related to aviation mishaps. Because CRM has succeeded in aviation training, other high-reliability industries such as the merchant navy, aviation maintenance, nuclear power generation, offshore oil production, and medicine have also adopted it.[5]

The purposes of the current study are to identify the nontechnical causes of Navy diving accidents and determine training requirements for a crew resource management course specifically designed to improve the safety and productivity of U.S. Navy dive teams. Salas, Prince, et al.[6] and Oser, Salas, Merket, and Bowers[7] identify operational/mission requirements to be trained as the first crucial step in developing a CRM course. With multifaceted methods for collecting data and with both quantitative and qualitative techniques, the nontechnical skills required to reduce the likelihood of a diving accident were identified. Using multiple techniques allows the advantages of one method to offset the disadvantages of another.[8]

METHODS

Four independent data collection methods were employed: analysis of mishap reports, analysis of reports investigating fatal mishaps, critical incident interviews, and questionnaire surveys.

ANALYSIS OF MISHAP REPORTS

Dive mishap reports sent to the Navy Experimental Diving Unit (NEDU) by the U.S. Navy Safety Center from 1993 to 2002 were used to examine the numbers, types, and causes of Navy diving mishaps. These reports provide information about the types of injuries, the types of underwater breathing apparatus (UBA) used, the purposes of the dives, and the causes of the accidents.

ANALYSIS OF REPORTS INVESTIGATING FATAL MISHAPS

Five Mishap Investigation Reports (MIR) were examined. These reports are required to answer the who, what, where, when, and why questions about on-duty diving accidents that resulted in Navy diving fatalities[9] that have occurred within the last 15 years. Three of the deaths were attributed to drowning; one, to an arterial gas embolism (AGE); and another to trauma.

Each of the five diving fatality accounts was content analyzed[10] by two independent raters (both experienced industrial/organizational psychologists, one of whom is a qualified Navy basic diving officer) to identify and code the statements relating to nontechnical skills into a set of thematic categories describing failures in those skills. The O'Connor and Flin[11] offshore operations nontechnical skills framework provided an initial structure to thematically organize the data.

CRITICAL INCIDENT INTERVIEWS

Originally developed to examine flight crew selection, readiness, and performance,[12] the critical incident technique evaluated systems and behavior in work environments. Since 1947 it has been used for more than a hundred different purposes in diverse disciplines.[13]

This technique was employed to aid respondents in recalling a diving accident or near-miss in which they had been involved. The critical incident method enables the researcher to identify the often tacit knowledge of skills and expertise respondents possess. It surpasses procedural knowledge by probing the behavioral aspects of experience. The critical incident interview uses recollection of a specific incident as its starting point and employs a semistructured interview format involving several "sweeps" through the incident. Specific, focused probes are used to elicit particular types of information such as cue utilization, context assessment, expectancies, and judgments. The four sweeps in the critical incident interview include:

Sweep 1 — Prompting the interviewee to identify a relevant incident and articulate it: each participant is asked to describe the event from his/her own perspective — to describe it in detail, stage by stage, as it developed.

Sweep 2 — Filling in gaps in the incident: the interviewer repeats the situation back to the respondent in order to check the interviewer's understanding. The respondent is told to correct any mistakes in the account or add any information that has been omitted during the recounting. This sweep helps to pinpoint gaps, both in time and events, and typically aids in recalling the missing portions.

Sweep 3 — Expanding on the incident to look for cues and factors affecting teamwork: the interviewer reviews the event again, this time probing at various points and asking for more detailed descriptions of the teamwork during the situation. This sweep involves questioning the reasoning and looking for cues and rationales for judgments.

Sweep 4 — Posing "what-if" queries: a typical question might be, "Would you have acted the same way at an earlier point?" or "Would someone with less experience than you have acted in a similar way?" The researcher listens for other possible courses of action and interpretations.

Rather than transcribing the interview as it was conducted, a tape recording was used to develop a single full report of the incident. Following this process, as with the fatality reports, the accounts were subjected to content analysis.

QUESTIONNAIRE SURVEYS

A 27-item questionnaire was designed to measure diver attitudes to factors identified as correlates of safe performance (see Appendix A). The items in the questionnaire were adapted from those of the Cockpit Management Attitudes Questionnaire (CMAQ) and the Flight Management Attitude Questionnaire (FMAQ), two well-established, frequently used training, evaluation, and research tools developed to assess flight crew attitudes toward human factors issues.[14] The CMAQ and the FMAQ have been adapted for use in the military aviation, aviation maintenance, air traffic control, medical and nuclear power generation, and offshore oil and gas production industries.[15] The items from the questionnaire were postulated to fit into a four-factor structure that was tested with confirmatory factor analysis (see Results section). The four proposed factors included:

- The "openness to questioning" subscale (items 1, 5, 9, 14, 18, and 21) assesses both how willing senior personnel (namely, the master diver [MDV] and diving supervisor) are to accepting questions from junior divers and how open these senior team members are to being questioned. A low score on these items indicates a team culture of openness.

- The "information sharing" subscale (items 3, 6, 10, 12, 17, 19, 23, 24, and 25) assesses how well diving objectives and plans are communicated and team members are monitored. A high score on this subscale indicates high levels of information sharing within the team.

- The "personal limitations" subscale (items 2, 8, 11, 15, 16, 20, and 22) investigates how team members consider — and possibly compensate for — stressors and how they deny the effect of stressors on their performance. This subscale contains both positively and negatively worded items. However, for the purpose of the analysis, the positively worded statements are reversed, so that a low score on this subscale suggests a belief in one's imperviousness to stressors.

- The "power distance" subscale (items 4, 7, 13, and 26) examines the authority gradient between senior and junior team members (this scale was dropped from the analysis, however, because the distribution of data from these items had high skewness and kurtosis: see the results).

For each statement in the questionnaire, the degree to which participants agree was assessed with a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree; see Appendix A).

The attitude questionnaire was distributed to U.S. Navy divers at seven different Navy diving commands. In addition to responding to the 27 attitude statements, participants were asked to list what they believe to be the three main causes of U.S. Navy diving accidents (see Appendix A).

Questionnaire survey statistical analysis

For statistical analysis, completed questionnaires were returned to NEDU and entered into SPSS for Windows version 11.5 and EQS for Windows version 6.1. Several different analyses were performed: (1) item and scale analysis, (2) confirmatory factor analysis (CFA), (3) analyses of variance (ANOVAs), (4) comparison with military pilots, and (5) ranking of causes of accidents.

1. Item analysis. For each of the 27 items, the reliability of each of the proposed scales was assessed. The skewness, kurtosis, and the correlation between the items pertaining to each theme were evaluated. Cronbach's Alpha was also used as a measure of internal scale consistency. It calculates the reliability of the scale by specifying the proportion of the total variance which is unique for the set of items, subtracting this proportion from 1 to determine the proportion that is communal, and multiplying by a correction factor to adjust for the number of elements contributing to the calculation.[16]

The Alpha coefficient ranges in value from 0 to 1 and may be used to describe the reliability of factors: the higher its value, the more reliable the scale. Nunnally[17] has indicated 0.7 to be an acceptable reliability coefficient, but low thresholds are sometimes quoted in the literature. For example, in the CMAQ Cronbach's Alphas between 0.47 and 0.67 on its three scales were found.[18] However, indices with low scores do not necessarily invalidate the findings; low alphas can reflect the diversity of the constructs being measured.

2. Confirmatory factor analysis. A CFA technique was used to assess whether the proposed model of the relationship between the items and factors was valid. CFA seeks to determine whether the number of factors and the loadings (indicators) of measured variables on them conform to what is expected on the basis of preestablished theory. The researcher's a priori assumption is that each factor is associated with a specified subset of indicator variables. A minimum requirement of CFA is that the researcher hypothesize beforehand not only what number of factors are in the model but also which variables will load on which factors.[19] A linear structural relations approach to CFA, as implemented in EQS for Windows, was used to assess the factor structure of the attitude questionnaire.

The adequacy of models is assessed through many fit indices, the most frequently used of which is the chi-square (χ^2) statistic. A small, nonsignificant χ^2 value indicates that the observed data are not significantly different from the proposed model. Since "trivial" variations in fit, particularly with large sample sizes, can easily produce a statistically significant large χ^2 result,[20] indices have been developed to address this problem. However, no single index is sufficient for an absolute assessment of fit, and it is suggested that researchers use one index from each main family.[21] Tomas and Oliver[21] recommend using the χ^2 statistic in association with the Comparative Fit Index (CFI), Goodness of Fit Index (GFI), and Root Mean Square Error of Approximation (RMSEA).

The CFI is an incremental fit index that produces a statistic ranging from 0 to 1.[22] Incremental fit indices measure the proportionate improvement in fit by comparing a target model with a restricted baseline model.[23] The Satorra-Bentler scaled χ^2 statistic can also be used to adjust the CFI for a lack of normality of the data. This adjusted statistic is called the robust CFI.

The GFI is an absolute fit index: it directly assesses how well a model reproduces the sample data.[23] The GFI performs better than any other absolute fit index, and sample size causes only a small bias.[24] For both the CFI and GFI, a value of 0.9 is considered to be the minimum required to accept a model.[25]

The RMSEA is based on sample size, the noncentrality parameter, and degrees of freedom for the target model.[25] MacCallum[26] argues that the RMSEA is probably better than any other index when models are extremely parsimonious, as is the model used in this study. Browne and Cudeck[25] suggest that models that produce RMSEA values greater than 0.1 should be rejected, while models that are good descriptors of the data should produce RMSEA values of less than .05.

Adaptations to the model can be performed with the Lagrange Multiplier (LM) test, and the Wald test. The LM test makes recommendations about addition parameters that should improve the model fit, and the Wald test examines whether any unnecessary parameters are being estimated in the model.[27] The modification of the original model is arguably against the ethos of classical confirmatory factor analysis, where the proposed model either does or does not fit. However, it provides a useful mechanism for making some adaptations to the items retained in the questionnaire. An important caveat central to any adding or deleting of parameters is that any changes made to the model be founded in theory and not made simply because they improve the fit of the model.

3. Between groups comparisons. The mean scores on each of the questionnaire subscales were compared on the bases of three independent variables: type of diver, military rank, and years of diving experience. It was impossible to use a three-way ANOVA, since some groups would contain no individuals — e.g., enlisted divers who are basic diving officers, or inexperienced and junior-ranked first-class divers. Therefore, it was necessary to use one-way independent ANOVAs to examine each variable individually.

4. Comparison with military pilots. A comparison was made between the responses to 13 items common to both the diver attitude questionnaire and Reid's similar survey of

50 U.S. Air Force KC-10 pilots.[28] The KC-10 is a multicrew aircraft used by the U.S. Air Force to carry out inflight refueling and transportation. This comparison is of interest because Air Force pilots receive five phases of CRM training during their careers,[29] so they should be more attuned to human factors issues than divers are.

5. Ranking of accidents causes. When respondents were asked to list the three main causes of diving accidents, the overall scores for the causes of diving accidents were calculated as follows: the number of respondents who ranked a cause in position 1 was multiplied by 3; the number who ranked that cause in position 2 was multiplied by 2; and these products were added to the number of respondents who ranked this cause in position 3. The sum of these rankings gave an overall score for the cause of each accident.

RESULTS

ANALYSIS OF MISHAP REPORTS

A total of 455 dive mishap reports from 1993 to 2002 were examined. Ninety-seven recreational diving and 95 experimental reports were excluded: this study does not focus on recreational divers, and experimental dives were excluded because those reported mishaps resulted from tests of decompression tables in which some decompression sickness (DCS) was expected. The findings are summarized in Figure 1: DCS was the most common diving injury reported, and AGE was the second most frequent mishap.

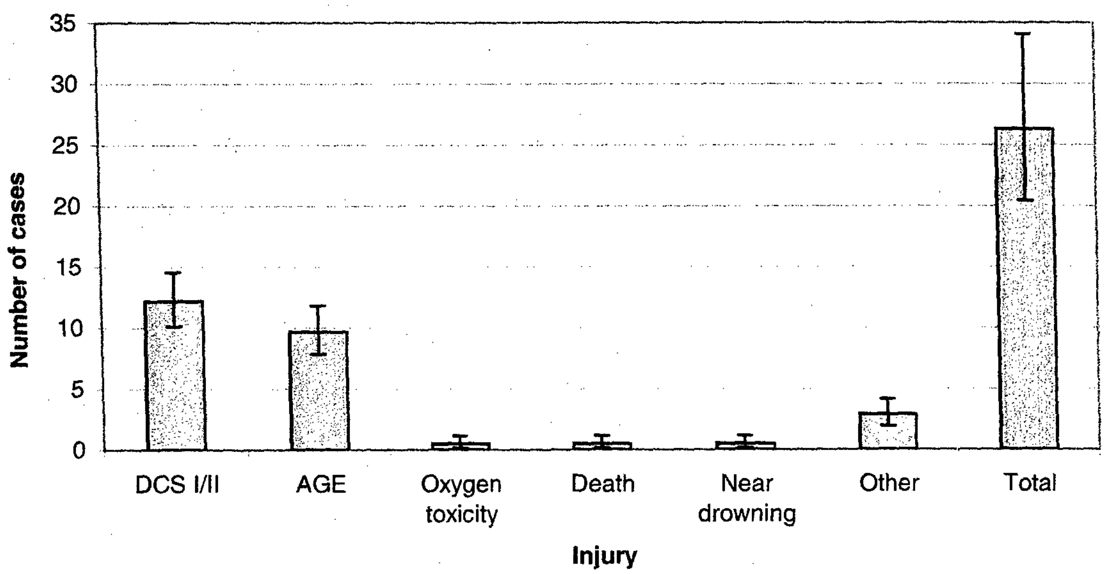

Figure 1. Mean incidents of U.S. Navy diving mishaps per year (whiskers represent a 95% confidence interval, based upon a Poisson distribution).

The mishap reports also allowed us to categorize causes of the diving mishaps. Table 1 shows that most of these mishaps were attributed to unknown causes, with almost one-quarter ascribed to human factors.

Table 1.
Causes of Mishaps Identified in the Mishap Reports.

Causes	Percentage
Unknown	70%
Human factors	23%
Mechanical failure	3%
Environment	2%
Physical overexertion	2%

ANALYSIS OF REPORTS INVESTIGATING FATAL MISHAPS

Each of the five diving fatality accounts was content analyzed[10] by two independent raters (both experienced industrial/organizational psychologists, one of whom is a qualified basic diving officer) to identify and code the statements related to nontechnical skills into a set of thematic categories describing failures in those skills. A total of 154 statements were so categorized. The O'Connor and Flin[11] offshore operations nontechnical skills framework provided an initial structure to categorize the data by themes.

When the categories identified by each rater were compared, areas of agreement and disagreement were discussed. On this basis, six categories were found to be sufficient to describe the failures in, and the effective use of, nontechnical skills in the five fatal accidents. However, it was necessary to make some changes to the O'Connor and Flin framework to accommodate the diving data (e.g., task awareness, team climate, choice of leadership style, and experience/training). This process produced an initial classification system consisting of six categories and 21 underlying elements (Table 2).

The interrater reliability was 64%, which is fairly low.[30] After a subsequent review of areas of agreement and disagreement between the coders was carried out, the data was recoded and an 84% agreement between the two raters resulted.

Table 2 shows the final frequency with which the elements were used to classify failures in nontechnical skills that caused the accident. Poor leadership, poor situation awareness (particularly risk and time assessment), poor supervison/leadership, and lack of personal resources were the most commonly used categories and elements. The numbers in parentheses in Table 2 represent the percentage of good examples of the behavior.

Table 2.
Diver Nontechnical Skills Framework.

Category	Element	Description	Example obtained from interviews	Interviews	Reports
Situation Awareness	Anticipation	Forward planning is completed to identify and discuss contingency strategies and/or possible future problems.	*Started screw change, he had done a dozen in the past*	1.1 (1.1)	6.5 (0.7)
	Problem definition/ diagnosis	Information is gathered to identify a problem and its causal factors.	*They did not want to admit something had gone bad.*	4.5	0.7
	Risk and time assessment	An accurate assessment of risk and time is completed (weather, sea state, time available, equipment, etc.)	*The whole evolution felt unsafe.*	19.2 (0.6)	20.1 (3.2)
	Dive status awareness	Every team members has an accurate awareness of how a dive is progressing.	*After about 30 minutes, getting no line-pull signals.*	11.3	7.8 (1.4)
	Task awareness	The team member has an accurate awareness of the task in which he/she is engaged and their role in the dive.	*Told he was red diver, then told he was yellow. Went over to yellow bike, then told he was red diver.*	3.4 (1.1)	4.5
	Concentration/ avoiding distraction	The team member is able to give the attention necessary to perform the task.	*The supervisor said to load a HeO_2 bottle, but he loaded an N_2O_2 bottle instead.*	2.3 (0.6)	
	Total			**41.8 (4.0)**	**39.6 (5.3)**
Decision Making	Procedural adherence	The procedures are followed correctly, and are appropriate for the task being carried out.	*The correct procedure was not followed to check the equipment.*	2.8	2.6 (0.7)
	Outcome review	The outcome of a solution is checked against the predefined goal.	*Nothing was learned from the incident.*	1.1	
	Total			**3.9**	**2.6 (0.7)**

Table 2. (continued)

Category	Element	Description	Example obtained from interviews	Interviews	Reports
Communication	Assertiveness/ speaking up	Ideas and observations are communicated in a manner that is persuasive to other team members.	*He suggested diving would not be a good idea but did not want to push it, as he knew he would be overruled.*	2.8 (0.6)	2.6
	Information exchange	Information is clearly and accurately exchanged between team members.	*He would not listen to recommendations.*	5.7	3.2 (0.7)
	Total			**8.5 (0.6)**	**5.8 (0.7)**
Teamworking	Team climate	Team members are aware of the competencies of their teammates, trust each other, and have a positive attitude toward being a member of the team.	*He requested extra divers, but they were reluctant to work outside normal working hours.*	4.6	2 (0.7)
	Conflict solving	Conflicts are resolved in a way that minimizes harm done to both parties.	*The shipyard viewed them as taking their work and so were not particularly helpful.*	0.6	(0.7)
	Total			**5.2**	**2.0 (1.4)**
Personal resources	Identifying & managing stress	Signs of stress are communicated and taken into account.	*There was a lot of tension topside.*	3.4 (0.6)	3.9
	Identifying & managing fatigue	Signs of fatigue are communicated and taken into account.	*They were diving around the clock, so the divers were tired.*	2.3	2.6 (0.7)
	Physical & mental fitness	Team members are sufficiently physically and mentally fit to perform the assigned tasks.	*He felt as if he was in a daze.*	1.1	0.7
	Experience/ training	The team members involved in the operation have sufficient experience and training.	*For many of the divers, it was the first time in a dry suit.*	6.8 (1.1)	7.8
	Total			**13.6 (1.7)**	**15.0 (0.7)**

Table 2. (continued)

Category	Element	Description	Example obtained from interviews	Interviews	Reports
Supervision/ Leadership	Appropriate use of authority	The supervisor adequately balances assertiveness and team member participation.	*He told the divers they were a bunch of pussies and he would get in the water if they were too scared.*	2.8	1.9
	Maintaining standards	The supervisor ensures the dive team complies with standard operating procedures and intervenes if required.	*They should have used the MK 21 for this evolution.*	10.2	10.4
	Planning and coordination	The appropriate personnel, resources, and techniques are selected to complete a task.	*There was some question about splashing a new diver who had never been in these conditions before.*	3.4	12.3
	Workload management	Tasks and resources are shared in order to achieve top performance and avoid workload peaks and dips.	*They knew there were jobs piling up behind them.*	2.3	1.3
	Choice of leadership style	A leadership style is used that promotes a safe working environment and is appropriate to the dive team, task, and urgency of the situation.	*The MDV was a cowboy.*	2.8	1.3
	Total			**21.5**	**27.2**

CRITICAL INCIDENT INTERVIEWS

A total of 15 critical incident interviews were completed. Two of the incidents resulted in a death of an individual, one in a near drowning, another in a serious physical injury, and the remaining 11 were near-misses in which no injury resulted although the potential for death or serious injury was high.

The same content analysis technique used to categorize the fatality account was employed to code the statements obtained from the critical incident interviews. A total of 163 statements were thematically categorized. The framework of categories and the elements developed from the fatality accounts and outlined in Table 2 were used to classify the statements from the interviews. The framework was found to be sufficient to describe the statements from the critical incident interviews: the interrater reliability between the two coders was 88%. Table 2 shows that the proportion of statements assigned to each category and element is broadly similar to that of the fatality report categorizations.

QUESTIONNAIRE SURVEYS

A total of 272 attitude questionnaire responses were obtained from U.S. Navy divers from eight different diving commands. Responses were obtained from 55 second-class divers, 148 first-class divers, 12 master divers, 26 basic diving officers, and 20 diving medical officers. The mean age of the respondents was 34.1 years (standard deviation = 6.6), with a mean of 10.4 years (standard deviation = 7.1) of Navy diving experience. Only five responses were obtained from female divers.

Item analysis

The skewness and kurtosis of each item were assessed. Ferguson and Cox[31] recommend a heuristic that at least 60% of items not have coefficients exceeding ±2 for multivariate analysis. This heuristic is important for CFA, as this technique assumes univariate and multivariate normality (the sum of all the variables associated with a particular factor are normally distributed).[27]

Eight items (4, 8, 13, 17, 19, 24, 26, and 27; see Appendix A) were found to have excessively high levels of skewness and kurtosis, so these items were dropped from further analysis. Two of these dropped items were from the "power distance" subscale and, as this factor consisted of only three items, we decided to drop it entirely from the analysis. Even after these items were removed, however, all the remaining items had levels of skewness or kurtosis exceeding ±2. Examining the Cronbach's Alpha scores for each of the three remaining subscales showed that they were acceptable for this survey: "Openness to questioning," $\alpha = 0.81$; "Information sharing," $\alpha = 0.66$; and "Personal limitations," $\alpha = 0.63$.

Confirmatory Factor Analysis

The 19 remaining items were entered into a CFA. To achieve an acceptable fit, it was necessary to drop item 20 (*personal problems can adversely affect my performance*) and allow item 25 (*effective crew coordination requires team members to consider the personal work styles of other divers*) to load onto the "Openness to questioning" factor. The final three-factor, 18-item model was found to acceptably fit the data, as a robust CFI of 0.90 and an RMSEA of less than 0.05 indicate. It was appropriate to use the robust CFI, as the normalized estimate of Mardia's coefficient of multivariate kurtosis was greater than 20 (see Fig. 2).[22]

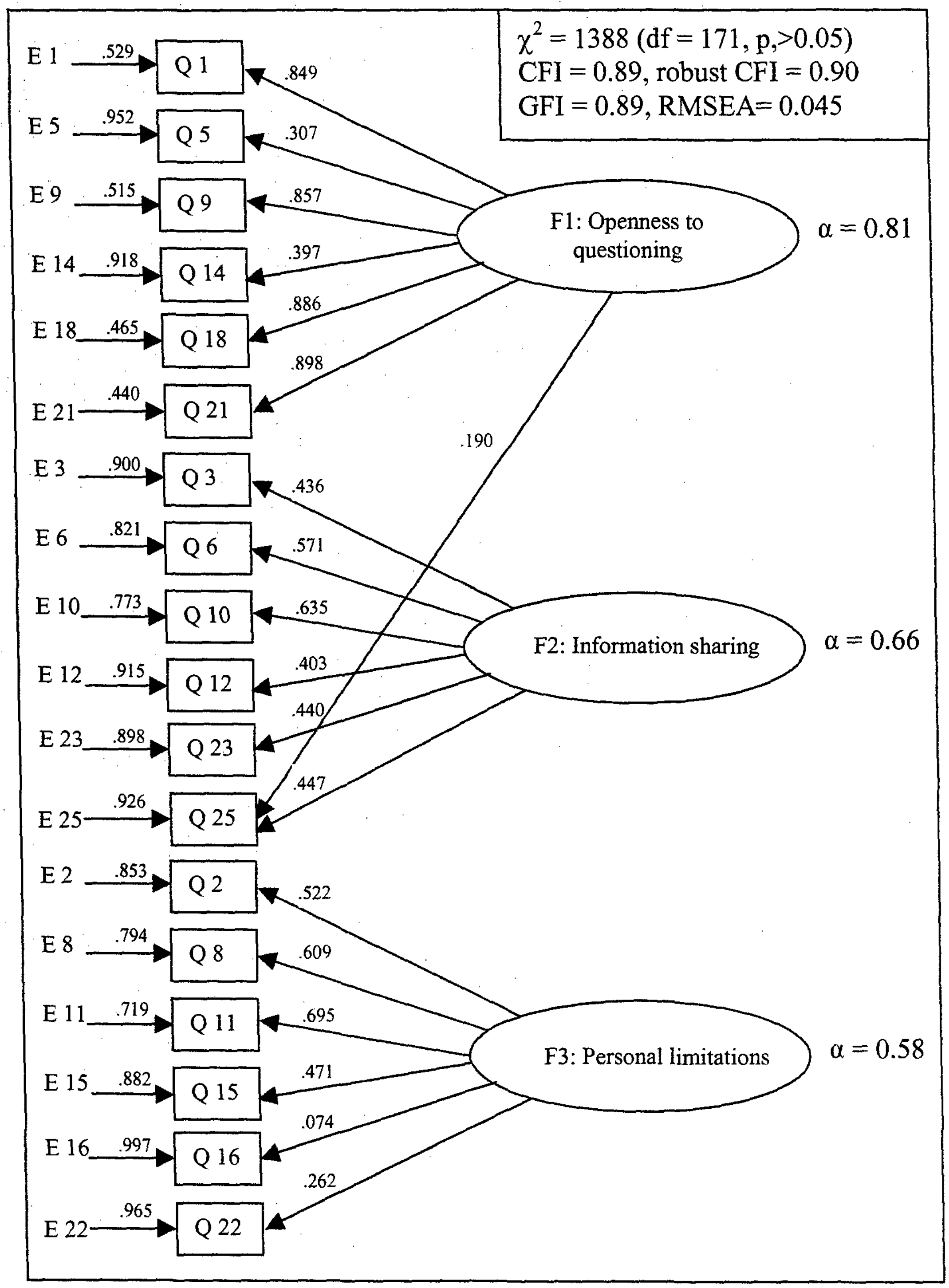

Figure 2. Standardized solution for the three-factor model.

Between groups comparisons

Types of divers. A total of 55 second-class divers, 148 first-class divers, 12 master divers (combined with first-class divers for analysis), 26 basic diving officers, and 20 diving medical officers (combined with basic diving officers for comparison) responded to the survey. Between subjects, ANOVAs showed that first-class divers have a significantly higher score on the "Openness to questioning" scale than second-class divers or diving officers and diving medical officers ($F_{(2,222)} = 8.07$, $p < 0.05$). There were no significant differences between the groups on the "Information sharing" scale ($F_{(2,263)} = 1.55$, n.s). Officers scored significantly lower on the "Personal limitations" scale than did first-class divers ($F_{(2,263)} = 5.64$, $p < 0.05$; see Fig. 3).

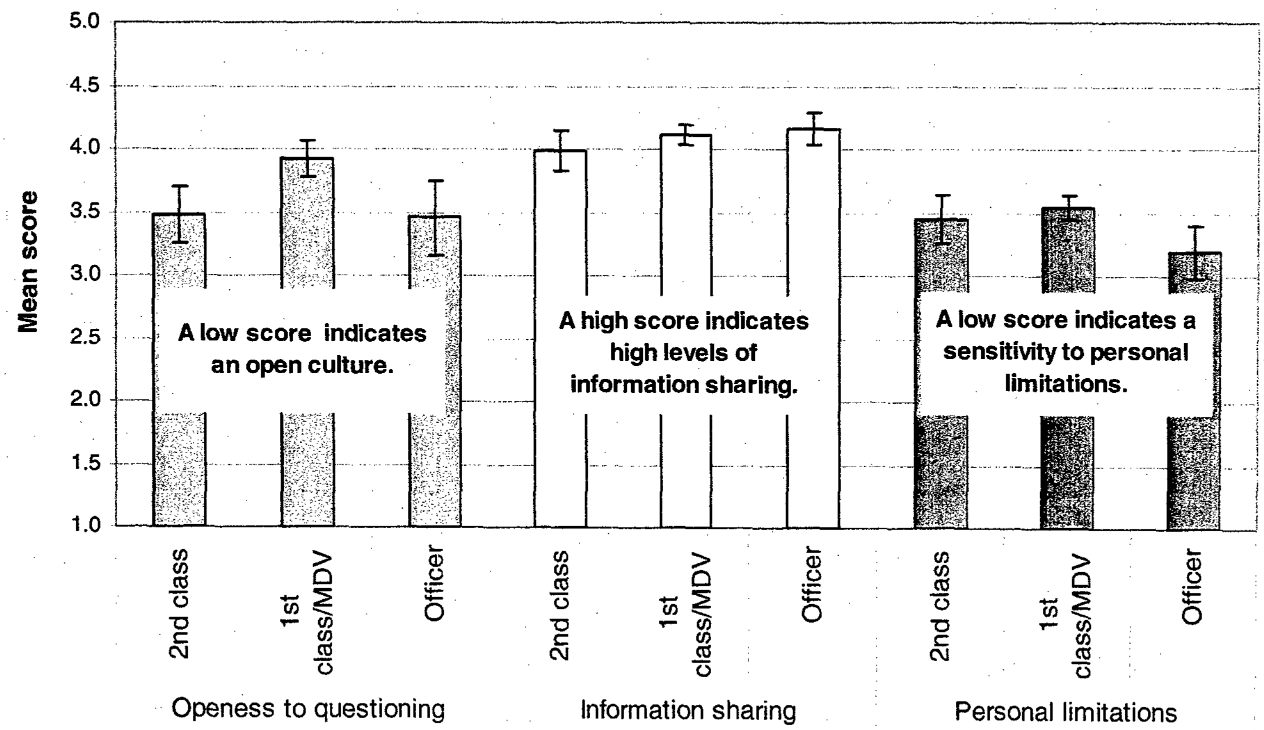

Figure 3. Mean attitude scale scores for type of diver (with whiskers representing a 95% confidence interval).

Rank of diver. Of the divers surveyed, 131 respondents were ranked from E4 to E6, 51 from E7 to E9, and 42 were officers (see Fig. 3). Divers ranked from E7 to E9 scored significantly higher on the "Openness to questioning" scale than did both those divers ranked E4 to E6 and officers ($F_{(2,221)} = 6.18$, $p < 0.05$). Although there were no significant differences between the groups on the "Information sharing" scale ($F_{(2,265)} = 2.87$, n.s), the F-test was approaching significance. Officers scored significantly lower on the "Personal limitations" scale than did divers ranked E4 to E6 ($F_{(2,263)} = 7.81$, $p < 0.05$; see Fig. 4).

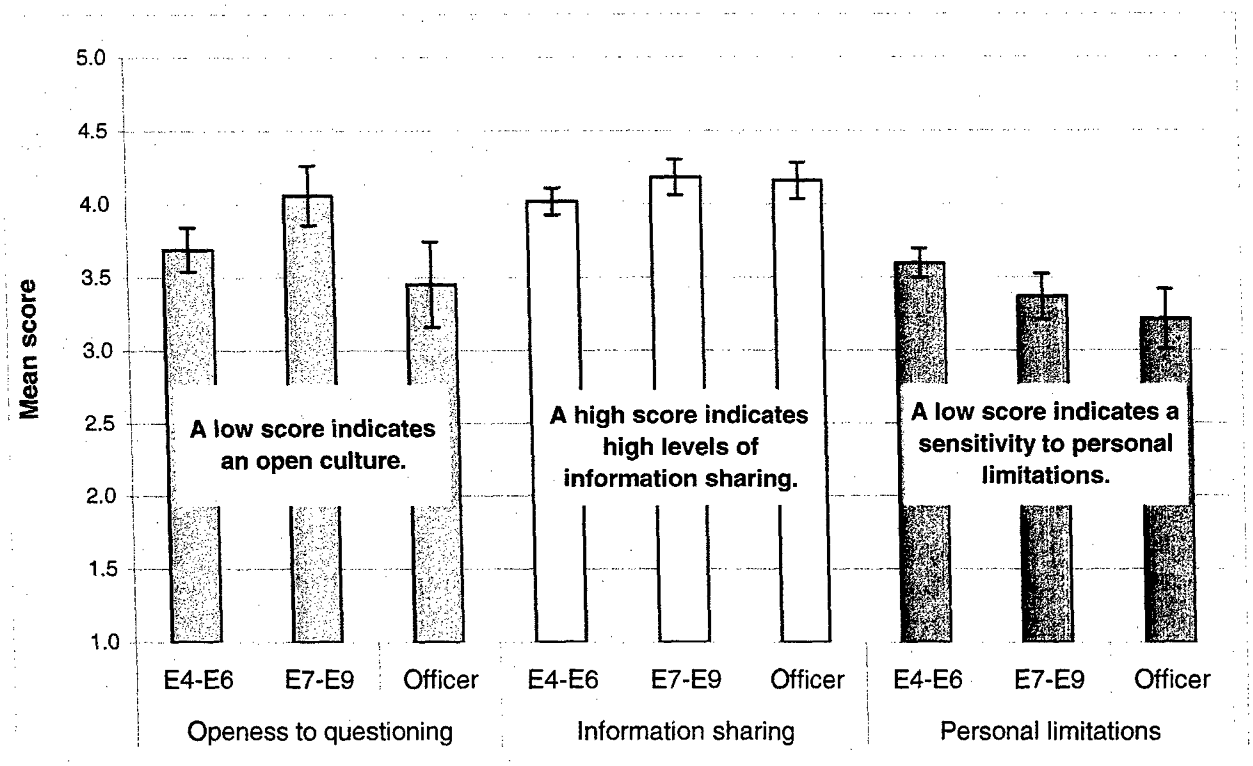

Figure 4. Mean attitude scale scores for rank of diver (with whiskers representing a 95% confidence interval).

Years of military diving experience. The respondents were divided into five groups on the basis of their number of years of diving experience. Thirty-six respondents had 0 to 2 years, 42 had 3 to 5 years, 45 had 6 to 10 years, 50 had 11 to 15 years, and 38 had greater than 15 years of diving experience (see Fig. 5). Based on their years of diving experience, no significant differences between groups were evident for the "Openness to questioning" ($F_{(4,206)} = 0.76$, n.s.), "Information sharing" ($F_{(4,250)} = 0.04$, n.s.), or "Personal limitations" ($F_{(4,250)} = 0.98$, n.s.) scales.

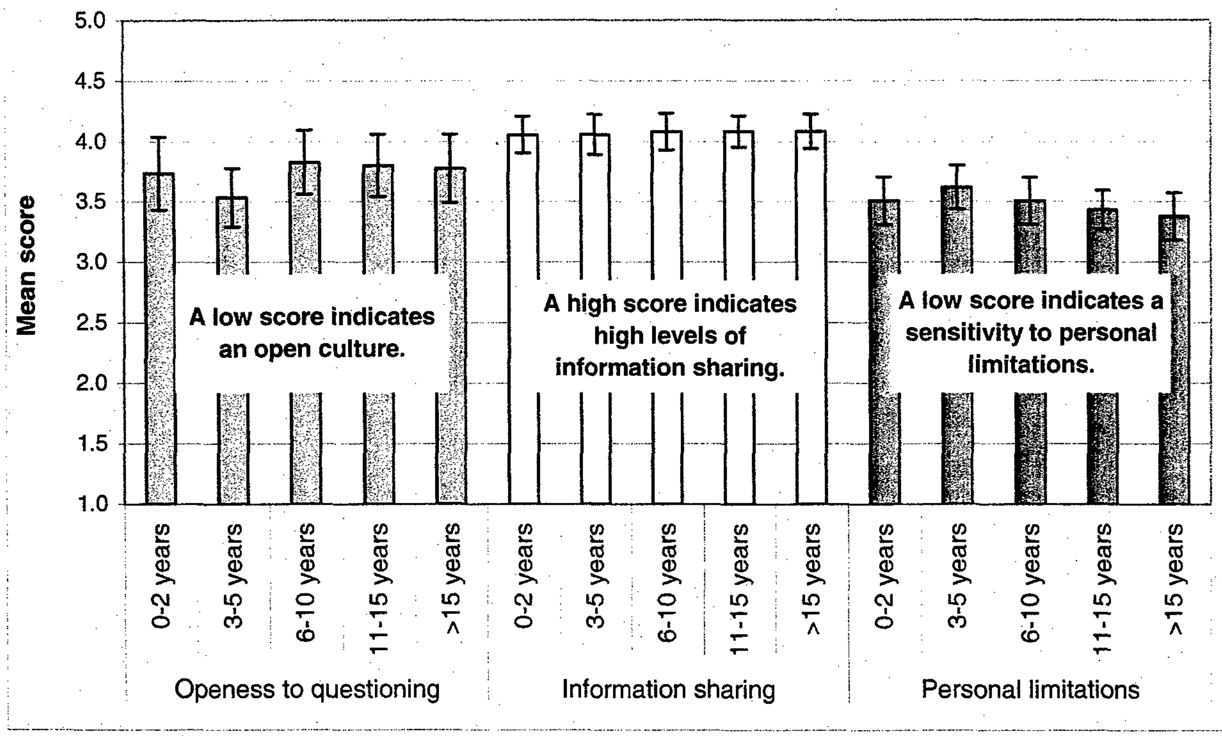

Figure 5. Mean attitude scale scores for years of military diving experience (with whiskers representing a 95% confidence interval).

Comparison with KC-10 pilots

Table 3 demonstrates that on those items common to both the diving and KC-10 pilot surveys, the pilots tended to have a more open attitude to being questioned by other team members and a greater sensitivity to the effects of stress and fatigue on human performance than the divers did. In Table 3 the items in italics are negatively worded, and square brackets indicate the wording of the item in the KC-10 questionnaire.

Table 3.
Mean item scores for divers and KC-10 pilots.

	Item	Divers	KC-10 pilots
	Factor 1: Openness to questioning		
5.	*Divers [crew members] should not question actions of the Dive Supervisor [Aircraft Commander], except when they threaten the safety of the dive.*	*3.8*	*1.7*
14.	*Divers [crew members] should not question actions of the MDV [Aircraft Commander], except when they threaten the safety of the dive.*	*3.6*	*1.7*
	Factor 2: Information sharing		
6.	I let other divers [crewmembers] know when my workload is becoming (or is about to become) excessive.	3.6	3.9
23.	Divers [crewmembers] should mention their stress or physical problems to other team members before or during a dive.	3.9	3.8
	Factor 3: Personal limitations		
2.	*Even when fatigued, I perform effectively during critical times in a dive [flight].*	*3.6*	*2.6*
8.	*My decision-making ability is as good in emergencies as in routine diving operations [flying conditions].*	*4.1*	*3.8*
11.	I am more likely to make judgment errors in an emergency.	2.5	2.6
15.	I am less effective when stressed or fatigued.	3.3	4.1
16.	*My performance is not adversely affected by working with an inexperienced or less capable diver [crewmember].*	*3.3*	*3.0*
22.	*A truly professional diver [A true professional] can leave personal problems behind when diving [flying].*	*3.6*	*2.7*
	Dropped Items		
19.	Divers [Crewmembers] should monitor each other for signs of stress or fatigue.	4.6	4.5
20.	Personal problems can adversely affect my performance.	3.5	4.0
27.	*A true professional does not make mistakes.*	*1.4*	*3.8*

<u>Ranking of accident causes.</u>

Table 4 shows that complacency, fatigue, and inexperience were the three most commonly identified causes of diving accidents. However, diver situation awareness was the fourth most common cause of such accidents that second-class divers chose. Planning, the most commonly chosen cause among diving officers, was the third most commonly chosen cause among master divers and warrant officers.

Table 4.
Top eight causes of diving accidents identified by different groups of U.S. Navy divers.

Cause	All	2nd-class	1st-class	MDV/WO	BDO	DMO
Complacency	**1**	**2**	**1**	**2**	**3**	**2**
Fatigue	**2**	**3**	**2**	**1**	**=5**	**1**
Inexperience	**3**	**1**	**3**	**=5**	**2**	**4**
Training	**4**	=6	**4**	**=5**	**4**	**3**
Planning	**5**	9	**5**	**3**	**1**	=11
Communication	6	=6	6	**4**	**=5**	=6
Rushing	7	**5**	7	=13	=11	=11
Dive situation awareness	8	**4**	8	=13	8	=9

MDV/WO is a master diver/warrant officer.
BDO is a basic dive officer.
The equals sign means that more than one category was ranked at this level.

DISCUSSION

ANALYSIS OF MISHAP REPORTS

Analysis of the dive mishap reports revealed that the largest proportion of mishaps are attributed to unknown causes. Three possible reasons may account for this finding. First, a certain proportion of mishaps in diving, unlike those in any other industry, are expected. Even if decompression tables are used correctly, a certain number of DCS cases are expected — because of the probabilistic manner in which these tables are constructed.[32] Therefore, even if a dive is carried out perfectly, a diver still has a chance, however small, of getting DCS.

A second possible reason is a lack of understanding about what "human factors" actually denotes. This uncertainty is not confined to U.S. Navy diving: oil exploration companies have also not coded human factors causes of accidents consistently.[33]

A third possibility is in a reluctance to provide a detailed, accurate account of mishaps, an unwillingness evident from the great variation in the quality of mishap reports. The U.S. Navy diving community has recognized this lack of will to complete a dive mishap form, however, and is seeking to improve the quality of the information collected.

ANALYSIS OF FATAL MISHAPS REPORTS AND CRITICAL INCIDENT INTERVIEWS

The diver nontechnical skills framework (see Table 2) developed with data from the fatal mishap reports could be used in various ways to improve the investigation of diving accidents, the training of divers, and the evaluation of divers.

Using the framework to categorize the human factors causes of the 15 incidents or near-misses collected in the critical incident interviews demonstrated its value in accident investigation. The framework could be used without alterations being necessary, and this fact adds supporting evidence that the nontechnical skills framework is a valid, reliable structure for categorizing the human factors causes of diving accidents.

The diver nontechnical skills framework (Table 2) could also aid in identifying human factors skills in which divers must be proficient and in developing criteria for evaluating and providing feedback on performance to diving supervisors or MDVs in training. In the aviation industry, behavioral markers are used to conduct training in and to evaluate nontechnical skills. These markers are a prescribed set of behaviors indicating some aspects of skilled human performance.[34,35,36] The use of such markers in training first-class divers, basic diving officers, and master divers at dive school could provide an objective basis for giving students feedback on their performance.

That leadership failures were evident in detailed reports of diving fatalities is not surprising. Research studies in high-reliability industries have identified management commitment to safety as the single most important factor in determining organizational safety performance.[5]

Failures in situation awareness and in risk and time assessments are also expected human factors causes of mishaps. Sarter and Woods regard situation awareness as "*an essential prerequisite for the safe operation of any complex dynamic system*".[37] It is necessary for each member of a team not only to understand what he or she is doing but also to know what other members of the team are, or are not, doing.[38] In a review of more than 200 aviation mishaps, Hartel, Smith, and Prince[39] find that a lack of situation awareness is the greatest causal factor in Navy and Marine aviation mishaps. Thus, as in aviation, a superior situation awareness characterizes safe diving.

QUESTIONNAIRE SURVEYS

Item analysis and confirmatory factor analysis. Eliminating nine items from analysis in the diver attitude questionnaire was necessary because of problems with part of the CRI process or with excessive skewness or kurtosis. The process of discarding items is common in questionnaire development.[16] Measures are continuously changed as more data become available. To illustrate, the offshore risk assessment questionnaire developed for use with offshore workers by Flin, Mearns, Fleming, et al.[40] consisted of 14 sections and 216 items. Following refinements and another three iterations, the most recent version of the offshore safety questionnaire consists of only six sections and 64 items.[41]

The CFA process resulted in a stable three-factor structure, and the reliability of the three scales appears to be acceptable for this type of attitude questionnaire.

Comparisons between groups. Responses to the attitude questionnaire showed that, when the attitudes of second-class divers or diving officers are compared to those of first-class divers/MDVs, those latter groups are significantly less likely to believe that junior divers should question an MDV or a dive supervisor. Furthermore, officers are significantly more likely to be aware of the detrimental effect that factors such as stress and fatigue have on their performance than are first-class divers/MDVs.

Examining the attitudinal differences based on the divers' military rank, we found that divers ranked from E7 to E9 (almost all of whom were first-class divers) are significantly less likely than officers or divers ranked E4 to E6 (approximately two-thirds of whom were first-class divers) to believe that junior divers should question the MDV or dive supervisor. Officers also are more likely to be aware of how stress and fatigue affect performance than are divers ranked E7 to E9.

Heinrick[42] believes that the supervisor is the key in preventing industrial accidents. At the task level, supervisors hold huge influence on issues such as compliance with safety rules.[43] Mearns, Flin, Fleming, and Gordon[40] find that the offshore oil production supervisors most effective in terms of safety performance use interpersonal skills more often than do supervisors who are less effective: when these less effective supervisors are not directly involved in an operation, they abdicate responsibility for their subordinates' safety, focus on productivity and deadlines, and feel pressured to get the job done. North Sea divers also reported that their confidence in the supervisor's ability to manage the accident risk was the most important factor in preventing accidents.[44] Thus, the supervisory position and the attitudes and leadership skills of those in it are crucial to the safety and effectiveness of a diving mission.

Comparison with KC-10 pilots. From a comparison of items that were common to both the pilot and diver questionnaires, pilots seem to be more sensitive to the effects of stress and fatigue on their performance than divers are. However, the most striking differences are in the reluctance of divers to question the MDV or diving supervisor, in contrast to the willingness of pilots to question the aircraft commander (see also Appendix B, items 1, 5, 14, and 18). The finding that Air Force pilots are more sensitive to human factors skills than divers are is unsurprising: Air Force pilots receive formal training in situation awareness, crew coordination, communication, decision making, task management, and mission planning as part of their Air Force CRM training program, and this training is integrated into flight briefings, debriefings, and training syllabi. Furthermore, these pilot skills are evaluated during initial qualification and recurring evaluations.[29]

The failure to exchange information and coordinate actions is one factor that distinguishes good and bad team performance.[45] Research shows that high-performing teams have a climate of openness and trust, where team leaders are receptive to alternative views and team members are not afraid to express them.[46] The need for assertive behavior in junior team members has been sharply highlighted in aviation research. Foushee and Helmreich[47] report that on the flight deck, copilots are more reluctant to question the captain under emergency conditions, and this lack of assertiveness has contributed to aircraft crashes (e.g., Tenerife, 27 March 1977; Washington, 13 January 1982). In a simulator study Foushee and Helmreich also find further evidence that when aircraft captains feigned incapacity during a final landing approach, 25% of the planes "crashed" because the copilot had failed to assume control.[47]

Ranking of accident causes. Questionnaire respondents identified human factors rather than mechanical or environmental causes as the main sources of diving accidents. The most common causes of diving accidents they identified were complacency and fatigue. This response is consistent with findings from other high-reliability operations: complacency has been identified as the third and fatigue as the second most common cause of aviation maintenance errors,[48] and in a survey of the workforce on six U.K. offshore platforms, more than a third of the respondents cited a lack of care and attention as the most common cause of accidents.[40] Fatigue has also been identified as a factor in offshore oil production accidents, because of the long periods (14 to 21 days) of constant work. Miles[49] describes offshore accident rates and research in which the incidence of serious injury in relation to all injuries was found to increase with increasing tour time.

The third and fourth most commonly mentioned causes, respectively, are inexperience and training. This finding is of interest since the Navy is no longer doing the range of diving it has done in the past. Therefore, as experienced MDVs and supervisors retire, they may be replaced with people who have not had the opportunity to acquire the same amount of hands-on knowledge. Given the complexity and high stress in a real-world situation, one can never reproduce these stressors in a training environment.[50]

Differences in the rankings that different types of divers give for the most common causes of accidents seem colored by the roles these divers play on the dive team. Officers ranked poor planning as the greatest cause of diving accidents, and MDVs and warrant officers ranked planning as third. Second-class divers judged diver situation awareness to be the fourth greatest cause of diving accidents.

CONCLUSIONS

The collected data demonstrate that training of first-class divers or diving supervisors as well as basic diving officers would benefit from incorporating leadership instruction, developing and maintaining situation awareness, and assessing risk, time, and the effects that personal limitations have on performance. The use of CRM training seems to offer a palatable method for providing training in these nontechnical skills.

As the principal causes of human errors in U.S. Navy diving do not appear to differ greatly from those in aviation, the temptation may be simply to use exactly the same training as that given in aviation. However, if aviation CRM is to be adapted for a different audience, the training materials must be customized for the particular industry: training is not likely to be effective unless examples pertinent to the particular industry are used. One of the main criticisms from participants of the early aviation CRM courses was that there was too much psychological theory and not enough relevance to aviation: as Helmreich writes, "*I am not suggesting the mindless import of existing programs; rather, aviation experience should be used as a template for developing data driven actions reflecting the unique situation of each organization*" (p. 784).[51] Thus, CRM training needs to be tailored specifically for U.S. Navy military divers.

In view of the high-risk activities carried out by Navy dive teams, the rate of diving mishaps is remarkably low and is a laudable achievement. Nonetheless, effective teamwork and leadership can increase productivity and help maintain safe conditions in complex, stressful environments. The consequences of ineffective teamwork and leadership, on the other hand, can be catastrophic.

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APPENDIX A. DIVING HUMAN FACTORS QUESTIONNAIRE

NAVSEA Deep Submergence Biomedical Development has funded the Navy Experimental Diving Unit (NEDU) to provide a better understanding of the human factors skills required for safe and effective diving operations. By completing the attached questionnaire, you will be helping in this process. The questionnaire should take a maximum of five minutes to complete.

If you have any questions or comments, please contact LT Paul O'Connor, tel: 230 3257, email: paul.e.oconnor@navy.mil.

Please return the completed questionnaires to:
LT Paul O'Connor, NEDU, 321 Bullfinch Road, Panama City, FL 32407-7015.

Diving Human Factors Questionnaire

The success of the survey depends on your contribution, so it is important that you answer questions as honestly as you can. There are no right or wrong answers, and often the first answer that comes to mind is best. **Individual responses are absolutely confidential.**

Please answer the following items by using the following scale in writing your response beside each item:

A	B	C	D	E
Disagree Strongly	Disagree Slightly	Neutral	Agree Slightly	Agree Strongly

1. Junior divers should not question the MDVs' decisions in emergencies.
2. Even when fatigued, I perform effectively during critical times in a dive.
3. Divers should be aware of, and sensitive to, the personal problems of other team members.
4. I expect to be consulted on matters that affect the performance of my duties.
5. Divers should not question actions of the Dive Supervisor, except when they threaten the safety of the dive.
6. I let other divers know when my workload is becoming (or is about to become) excessive.
7. MDVs who encourage suggestions from divers are weak leaders.
8. My decision-making ability is as good in emergencies as in routine diving operations.
9. Junior divers should not question the Dive Supervisors' decisions during normal operations.
10. Divers should alert others to their actual, or potential, work overload.
11. I am more likely to make judgment errors in an emergency.
12. A debriefing after each dive is an important part of developing and maintaining effective teamworking.
13. In abnormal situations, I rely on my superiors to tell me what to do.
14. Divers should not question actions of the MDV, except when they threaten the safety of the dive.
15. I am less effective when stressed or fatigued.
16. My performance is not adversely affected by working with an inexperienced or less capable diver.

A Disagree Strongly	B Disagree Slightly	C Neutral	D Agree Slightly	E Agree Strongly

17. The predive brief is important for safety and effective teamworking.
18. Junior divers should not question the Dive Supervisors' decisions during emergencies.
19. Divers should monitor each other for signs of stress or fatigue.
20. Personal problems can adversely affect my performance.
21. Junior divers should not question the MDVs' decisions during normal operations.
22. A truly professional diver can leave personal problems behind when diving.
23. Divers should mention their stress or physical problems to other team members before or during a dive.
24. Good communication and crew coordination are as important as technical proficiency for dive safety.
25. Effective crew coordination requires team members to consider the personal work styles of other divers.
26. Dive Supervisors who encourage suggestions from divers are weak leaders.
27. A true professional does not make mistakes.

In your opinion, what are the three main causes of diving accidents?

1______________________________

2______________________________

3______________________________

Background Information.

Please circle the appropriate response.

Type of diver	Scuba	2nd-Class	1st-Class	DMT	MDV
	BDO	DMO	EOD	SEAL	Army
Rate	E1–E3	E4–E6	E7–E9	Officer	
Sex	Male	Female			

What is your age? __________

How many years have you been a Navy diver? __________

As a follow-up to this questionnaire, there is a requirement to carry out a number of interviews of divers about dives in which they were involved and which either resulted in an accident, or could have led to an accident. This interview will take a maximum of 45 minutes, and the information will be kept in the **strictest confidence**.

Do you agree to participate in the interview? Yes No

If yes, please provide your name and contact information. If you require further information, please contact Lt. Paul O'Connor, 230 3257, paul.e.oconnor@navy.mil

Name: ____________________

Contact information: ____________________

Thank you for taking the time to complete the questionnaire.
Your participation is appreciated.

PLEASE RETURN TO LT PAUL O'CONNOR, NEDU, 321 BULLFINCH ROAD, PANAMA CITY, FL 32407.

APPENDIX B. PATTERN OF RESPONSES TO THE DIVER ATTITUDE SURVEY.

	Item	Disagree	Neutral	Agree
1	Junior divers should not question the MDVs' decisions in emergencies.	21	7	72
2	Even when fatigued, I perform effectively during critical times in a dive.	24	14	63
3	Divers should be aware of, and sensitive to, the personal problems of other team members.	11	17	72
4	I expect to be consulted on matters that affect the performance of my duties	2	3	95
5	Divers should not question actions of the Dive Supervisor, except when they threaten the safety of the dive.	22	7	71
6	I let other divers know when my workload is becoming (or is about to become) excessive.	16	19	65
7	MDVs who encourage suggestions from divers are weak leaders.	93	3	4
8	My decision-making ability is as good in emergencies as in routine diving operations.	8	14	78
9	Junior divers should not question the Dive Supervisors' decisions during normal operations.	33	14	53
10	Divers should alert others to their actual, or potential, work overload.	5	11	84
11	I am more likely to make judgment errors in an emergency.	6	7	87
12	A debriefing after each dive is an important part of developing and maintaining effective teamworking.	6	7	87
13	In abnormal situations, I rely on my superiors to tell me what to do.	55	19	26
14	Divers should not question actions of the MDV, except when they threaten the safety of the dive.	25	10	65
15	I am less effective when stressed or fatigued.	26	18	57
16	My performance is not adversely affected by working with an inexperienced or less capable diver.	32	19	49
17	The predive brief is important for safety and effective teamworking.	3	3	94
18	Junior divers should not question the Dive Supervisors' decisions during emergencies.	16	10	74
19	Divers should monitor each other for signs of stress or fatigue.	3	3	94
20	Personal problems can adversely affect my performance.	24	14	61
21	Junior divers should not question the MDVs' decisions during normal operations.	23	10	67
22	A truly professional diver can leave personal problems behind when diving.	25	10	65
23	Divers should mention their stress or physical problems to other team members before or during a dive.	15	15	71
24	Good communication and crew coordination are as important as technical proficiency for dive safety.	1	1	98
25	Effective crew coordination requires team members to consider the personal work styles of other divers.	4	6	90
26	Dive Supervisors who encourage suggestions from divers are weak leaders.	94	2	4
27	A true professional does not make mistakes.	92	4	5

(n = 272, numbers are in percentages).